Measuring Mobile Broadband Networks in Europe

Open Call 2

Second MONROE Open Call for Experiments and Extensions

Characterising Mobile Content Networks in the Wild

(CaMCoW)

Main target of proposal	"Scientific Excellence"
Date of preparation of your proposal:	02/12/2016
Version number (optional):	
Your organisation(s) name(s):	Queen Mary University of London (QMUL)
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Note: Grey highlighted areas needs to be filled

Section A Project Summary

(Maximum 300 words – summary of the proposed work)

Remark: The information in this section may be used in public documents and reports by the MONROE consortium.

Mobile broadband (MBB) networks have seen dramatic increases in both capacity and uptake. Characterising user-facing network performance, however, can be challenging because it depends on the particular services being accessed by the subscriber. For example, a user accessing YouTube will receive different performance based on the provisioning and network distance between the access network and the nearest YouTube server. This is not simple - it is a product of both the MBB network and YouTube's interconnection and capacity planning strategies. Little substantive work exists on exploring the behaviour of user-facing services in MBB networks. This deficiency is particularly critical in MBB networks due to their relative dynamism, and less developed (IXP) peering models (compared to wireline infrastructures). *CaMCoW* will address this gap. It will exploit the MONROE testbed to measure the ways in which popular content services (e.g., Netflix, Google) have approached deploying and interconnecting their infrastructures for access by MBB subscribers. It will measure the deployment of these services and how MBB users are given access to them. We will correlate these deployment strategies with the Quality of Experience users can expect, to formulate and inform best practice. We will integrate data generated via CaMCoW with other (wireline) measurement studies we are performing in this area to gain a comprehensive view of wired and wireless behaviour. Through this, CaMCoW will *(1)* Explain how content services are currently provisioned and interconnected for access by MBB networks; *(2)* Provide data and analysis to describe the performance of each services and how it relates to their given deployment strategies; *(3)* Offer recommendations for improving user Quality of Experience when accessing these services from MBB networks; and *(4)* Generate detailed feedback for the MONROE consortium, e.g., bug fixing, improving accessibility for new users, streamlining measurement data collection, techniques for better automation of experiments.

Section B Detailed description and expected results

(minimum 4 to maximum 7 pages)

This section describes the details on the planned experiment and/or extension: what does the experimenter hope to obtain, how, why is it relevant? This section should also include all information with respect to the State-of-the-Art or a comparison to competing commercial solutions in case of experiments targeting 'industrial innovation' to show the innovative character of the experiment and/or extension, and the expected scientific or business impact.

B1 Concept and objectives

Describe the specific objectives of the proposed experiment and/or extension, which should be clear, measurable, realistic and achievable within the duration of the experiment and/or extension (not through subsequent development). Show how they relate to the topic(s) addressed by the competitive call and how/why MONROE is needed for realizing them.

Describe and explain the overall concept that forms the basis for your experiment and/or extension. Describe the main ideas, models or assumptions involved.

Mobile broadband (MBB) networks have seen dramatic increases in both capacity and uptake [**1**]. Despite these improvements, the user-perceived performance of an MBB network is not *solely* based on the network operator. This is because subscribers judge performance not from network-layer metrics but, instead, by the quality of experience (QoE) they perceive when interacting with the services they use, e.g., Facebook, YouTube. Consequently, the provisioning and interconnect strategies made by these services will directly impact how subscribers perceive the performance of their broadband. For instance, when web browsing, the major performance bottleneck is *not* access bandwidth but end-to-end latency between the subscriber and the server [**2**]; this means that web QoE is not driven by the MBB bandwidth, but by the distance between the subscriber and the web server (and the various interrelated factors, e.g., peering, congestion). This has led researchers to study how large organisations approach the deployment of content services [**3**]. Through wireline testbeds (e.g., Planetlab, RIPE Atlas), researchers have witnessed strategies such as inserting replica servers into edge networks [**4**], peering at Internet Exchange Points (IXPs) [**5**], adjusting transport layer settings [**6**], anycasting [**7**] and deploying specially designed application protocols [**8**]. There is a clear limitation in the research to date though: As of yet, these studies have been limited to wireline network operators. Little research has investigated how content service providers have *provisioned* and *interconnected* their services for cellular networks (e.g., via IXPs). Consequently, the efficacy of these choices in MBB environments is not clear. This is a significant shortcoming, as MBB networks will increasingly become used for heavy content distribution tasks [**1**]. Informing the best deployment strategy for providing content to an MBB is therefore critical. This, however, is currently difficult as MBB networks differ from traditional broadband in several ways. For example, in MBB networks, it can be difficult to geolocate clients for redirection to nearby servers [**9**] [**10**], DNS resolver configurations are often atypical [**11**] and virtual operators can introduce unexpected phenomena [**12**]. A key reason for these (poorly understood) differences is that we lack a detailed understanding of how content provider and MBB infrastructures interact and interconnect, preventing the community from proposing solutions. MONROE offers the ideal platform to explore this research challenge and redress the imbalance between wireless and wireline research in this field.

CaMCoW will take the first step towards addressing this deficiency by measuring the deployment, performance and (IXP) interconnection strategies of user-facing services, as perceived by clients connected to MBB networks. The findings will be used to explore the key performance bottlenecks in providing content services to MBB subscribers. Through this, we will enable superior future deployments, as well as propose incremental changes to existing ones. To achieve this, we require the MONROE testbed to be able to launch a comprehensive set of probes to discover and characterise how

the most popular content services are provisioned for MBB networks. We will initially focus on three key services: Google, Facebook and Netflix (as well as potentially others). We will build on our past work [**4**] [**5**] [**8**] [**13**] [**14**] [**15**] [**16**] and extend our methodologies. This will focus on using commodity tools (dig, wget, ping, traceroute), alongside bespoke techniques for detecting content-aware HTTP middleboxes, e.g., transparent caches [**17**]. Only through MONROE's ability to combine *both* MBB-side and content service-side measurements will it be possible to understand user-perceived performance. We define the following objectives of CaMCoW:

Objective 1: *To devise a reliable methodology for discovering the make-up and interconnection strategies of content service infrastructures (e.g., Google, Facebook) and MBB networks.* This objective will involve devising a software toolbox for discovering the location, path connectivity and performance of the servers providing popular content services from the perspective of end users in MBB networks. The toolbox will encompass a variety of measurement techniques to extract insights into content infrastructure deployment.

Measurable Outcome*:* The availability of a software toolbox that can be automatically deployed and executed on edge nodes in MONROE. This toolbox must contain all measurement techniques devised and produce standard measurement logs that can be returned to the experimenter for analysis.

Objective 2: *To compile datasets and analysis that characterises the content service infrastructure serving MBB* networks (e.g., location of servers, path characteristics). This objective will involve using the toolbox developed to run measurements across the MONROE testbed. Data will be collected that maps out the placement of the servers hosting popular services, as possible via the MONROE deployment and data allowances. Fine-grained information will be collected about the performance of accessing these services by MBB network subscribers. We will integrate this data with our existing measurement work (e.g., via RIPE Atlas) to compile a comprehensive view of wired and wireless infrastructure. This will be collectively used to understand the deployment strategy of content providers when serving MBB networks and how it relates to perceived performance.

Measurable Outcome: A comprehensive set of available datasets. These will cover the extent and the quality of the provisioning of services from the perspective of MBB networks within MONROE.

Objective 3: *To explain content service deployment strategies and propose a set of recommendations for the MONROE testbed, MBB networks and content service providers.* This objective will involve extending our measurements to understand the causality between a given level of performance (from poor to very good) and the corresponding deployment strategies of content service providers. Further measurements will be used to explore performance bottlenecks, based on the data and analysis performed in Objective 2. This objective will investigate how these factors differ across urban and rural setups for both static and mobile nodes. The iterative process will feed directly into a body of recommendations for improving the MONROE testbed and MBB/content provider deployments.

Measurable Outcome: A list of recommendations for the MONROE consortium, content providers and MBB networks (e.g., Telenor). These will make suggestions for how to improve the provision and measurement of future mobile content services. This will be disseminated to relevant parties to inform future content service infrastructure deployments, as well as to improve existing ones.

B2 Impact

For experiments targeting "Scientific Excellence": *Describe how this experiment fits in your internal research roadmap, and to which extent the broader research community can benefit from the results of the experiment.*

CaMCoW will generate *community impact* in two main areas. First, we will offer methodologies and datasets to shed light on how content services are provisioned and interconnected with MBB networks across Europe. This will be of interest to the Internet measurements community. It will also be of great

use to systems researchers, who will be able to build better informed solutions targeted at MBB networks. Interconnection strategies also have a significant role in measuring network resilience. Second, we will use our data to compile comprehensive feedback and recommendations for the MONROE consortium, MBB operators (e.g., Telenor) and content service providers. Our feedback will focus on the capabilities of MONROE in supporting measurements of user-facing systems; this will include feedback and suggestions on debugging, issues with node performance, system usability and reliability. A quality report will be generated for each service (e.g., Google, Netflix) to quantify their performance and bottlenecks when serving MBB networks. CaMCoW will also, for the first time, elucidate how large providers approach deploying their servers and network interconnections for MBB networks (e.g., do they peer with MBB networks?). This will allow us to correlate performance with deployment strategies to identify best practice. Through this, we will be able to compile recommendations for content service providers and network operators to improve their future strategies. This is particularly important for emerging MBB networks and content service providers, who may be approaching a stage where they wish to optimise their provisions. We will use QMUL's involvement in the IETF's Global Access to Internet for All research group to promote this, especially for networks oriented towards connecting new subscribers (e.g., in rural areas of Europe).

The proposal will also generate significant *internal impact* for our group's research roadmap. Performing mobile edge measurements is critical to our internal research efforts. QMUL has been active in deploying a variety of edge network measurements (e.g., studying middlebox deployment [**18**], content delivery systems [**19**], application behaviour [**15**]). These have been achieved via a range of novel methodologies, all of which have primarily focussed on wired infrastructures (e.g., using RIPE Atlas, VPNs, Planetlab). We have long been attempting to extend these measurements to gain vantage on the expanding cellular infrastructure. Gaining access to MONROE is critical for moving forward our Internet measurement research strategy. We plan to integrate MONROE with data from our past measurements (e.g., via Planetlab) to construct a more comprehensive understanding of content service infrastructure, further increasing impact. We currently have one PhD student, who will contribute to the project (Objectives 1 and 2).

***For any experiment and/or extension**: Show that the proposed experiment and/or extension have sufficient sustainable benefits for the MONROE project. Clearly indicate the added value for the MONROE project, especially after the proposer has finished his experiment or extension. Indicate any models that can help sustain and extend the MONROE platform and its usage beyond the project budget and project ending.*

The proposal will equip the MONROE consortium with a reusable and self-contained measurement toolbox for detecting and understanding how content services are provisioned for and interconnected with MBB networks. A key part of our proposal is understanding the reasons behind content service performance. This is knowledge currently lacked in the research community and will therefore likely generate high exposure for MONROE. This falls within the remit of the Application Performance Measurements experiments listed by MONROE's D1.1 (Report on Use Cases). We anticipate that performance variations will be attributable to various network-layer issues. Our proposal can therefore also feed into the Key Mobile Broadband Metrics use cases in D1.1. This will offer a bridge between these two groups of use cases and provide a powerful example of a measurement study that utilises both forms of data, expanding upon the discussion in [**20**]. This will provide validation for MONROE's effectiveness at supporting content/service oriented measurements. The diversity of measurements being performed will also provide insight into MONROE's ability to handle divergent forms of methodologies. We plan to make the data and software available to the wider MONROE team beyond the duration of the project. The toolbox will be available to form the basis for future studies via MONROE. This will widen MONROE's visibility and impact. Our toolbox will also allow the data that it generates both within and outside of MONROE to be integrated, thereby allowing further third party

studies to be published by extending our work onto other testbeds and comparing results against MONROE.

B3 Description of State-of-the-Art and Innovation Potential

For experiments targeting "Scientific Excellence": *Describe the advances the proposed experiment would provide beyond the state-of-the-art, and the extent the experiment is ambitious.*

Due to the dominance of certain content providers, it has been widely recognised that it is important to understand how large content providers approach deploying their infrastructures. This has led to a variety of studies looking at the operations and features of modern Content Delivery Networks (CDNs). QMUL has contributed heavily to this field, e.g., BBC iPlayer [**14**], Google CDN [**4**], Twitch [**15**] and other major web players [**16**]. State-of-the-art work [**3**] has, for example, mapped out the Google CDN, showing that Google uses both its own network and edge operators to deploy caches. Similar studies have been done for Netflix [**21**], showing how it spreads responsibility for distributing videos across multiple clouds. Other work has inspected particular sub-component of these CDN operations, such as Akamai's redirection strategy (based on network latency [**22**]). These, however, solely take vantage from traditional wired networks. CaMCoW will fill a critical gap, building upon these studies to understand and profile how these large CDNs approach deploying content for MBB networks. Exciting work has recently begun to investigate some of the critical elements of content delivery in MBB networks, such as DNS [**9**] and application layer protocol performance [**23**]. We are particularly interested in expanding our recent work on understanding the role of Internet Exchange Points (IXPs) in content infrastructure deployments [**24**]. We will significantly expand on this body of research to integrate considerations for both MBB network operators *and* live content providers, explaining the performance consequences of providers' deployment strategies. This is necessary because past approaches of using controlled measurement servers, rather than live public services, offer a distorted view of user-facing performance. Other related state-of-the-art work has measured edge performance [**25**] and compared cellular networks to wired infrastructures [**26**] [**27**] but, again, focus is not placed on the interdependencies between the cellular provider and the live content services (particularly their IXP-based interconnection strategies). This is insufficient to shed meaningful light on MBB network performance, as users can only gauge QoE from their interaction with real user-facing services. CaMCoW will therefore substantially expand upon the state-of-the-art to integrate these two, currently disparate, perspectives on mobile Internet activity. This will go well beyond simply characterising *how* the services are provisioned, and extend to understanding *why* they perform well/poorly. We will also broaden the existing state-of-the-art to cover performance issues faced at multiple layers in the stack, including software, middlebox, device and protocol factors. The proposal investigators have a strong history of successfully taking this multi-layer approach. These results will feed into improving service provision. For the first time, this will allow us to identify key performance bottlenecks, potentially supporting or rejecting recently proposed protocols, e.g., MPTCP [**28**] and SPDY [**29**].

B4 Methodology and associated work plan

Provide a work plan. Provide clear goals and verifiable results, and also a clear timing. Specify the milestones and deliverables. For proposals that have 2 participants, please clearly specify the roles and responsibilities for each of the participants.

To achieve our objectives we have devised a workplan, aligned with the phases proposed in the original proposal template. We have mapped these into a set of 4 key tasks that will primarily contribute to MONROE's WP3. These tasks have two core deliverables, as well as a number of milestones. The tasks, also shown in the Gantt chart in Figure 1, are as follows:

- Task 1: **Design and Execution of Experiments:** This involves building the measurement toolbox and executing it across MONROE nodes.

- Task 2: **Data Analysis and Experimental Revisits:** This involves analysing and potentially expanding our datasets to characterise the deployment setup and performance of content providers from the perspective of MBB subscribers.
- Task 3: **Feedback and Reporting:** This involves constructing detailed feedback for the MONROE consortium. It further includes providing feedback to MBB networks (e.g., Telenor) and content providers regarding the optimisation of content delivery to MBB subscribers.
- Task 4: **Dissemination:** This focusses on raising community awareness of our work, as well as MONROE more generally.

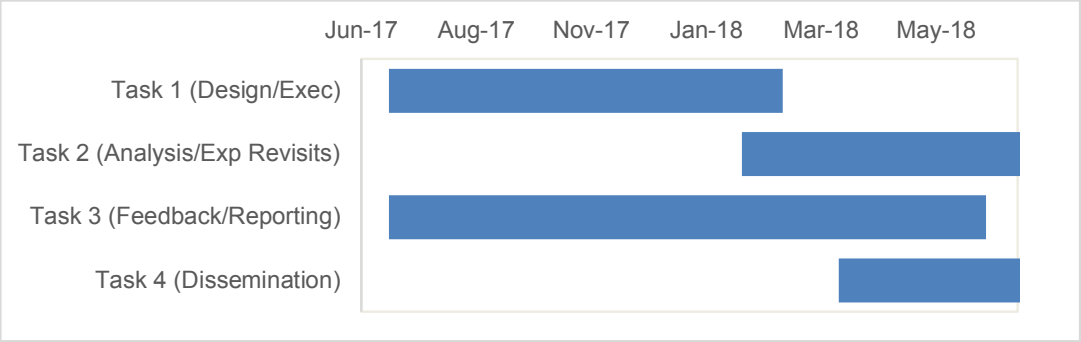

Figure 1 Gantt Chart of Task Execution

Task 1: Design and Execution of Experiments (Months 1-8)

The first Task will involve designing, implementing and deploying a measurement toolbox across the MONROE testbed; this will contribute primarily to MONROE WP3. This is captured by two milestones:

Milestone 1 (Month 4): Completion of prototype measurement toolbox. This will have already been deployed in a prototype phase, but by Month 4, a version will be available for usage by the MONROE consortium.

Milestone 2 (Month 8): Completion of first round of measurements collected using the toolbox. Attaining the above milestones will cover core elements of Objectives 1 and 2. The toolbox will be built iteratively with pilot deployments of the toolbox starting in Month 2; the results will feed back into subsequent versions across the following months. This toolbox will substantially expand upon past methodologies [**30**]. The experiments performed will be designed around two key measurement sub-tasks: *(1)* To collect a list of the server IP addresses serving MBB networks for all services under study, e.g., Google, Netflix etc; and *(2)* To measure the interconnectivity, and path characteristics from the MBB nodes to the servers hosting the service. These steps take inspiration from our recent work [**4**]. Information about the server provisioning will be augmented with further metadata, e.g., server geolocation, AS type, web server implementation. General network metadata will also be recorded in parallel, e.g., point of attachment, packet loss rate, round trip times, available bandwidth, presence of middleboxes. Due to their prominence, this will first focus on three web content providers: Google, Facebook and Netflix. The measurement toolbox will automate the collection of (at least) the following types of probes across all nodes and interfaces:

1. We will record the (IXP) interconnection points (if any) between the content servers and MBB networks. We will capture *path* characteristics (e.g., delay) and *topology* (e.g., inter-AS route, peering) between all MONROE nodes and all content servers observed (via paris-traceroute).
2. We will use various *public databases* to compile metadata about the servers and networks the MONROE nodes are redirected to, e.g., using Team Cymru, CAIDA, Maxmind. This will include their Autonomous System (AS), peering policy, network type and geolocation.

3. *Node-centric and network-layer data* will also be captured regarding MONROE nodes, where possible, including geolocation, point of attachment, signal strength, packet loss, available bandwidth, and jitter.
4. We will perform *full fetches* for the content/webpages under-study. This will only be performed periodically for "debug" purposes, to avoid exhausting data allowances for the nodes.
5. We will use *crafted lightweight HTTP messages* to detect middleboxes that may be intercepting our traffic. This will be used to understand the benefits of these middleboxes, as well as how they interplay with the origin content servers (e.g., reducing load by caching).

The collection of the above data forms the basis of Milestone 2 in Month 8. To capture mobility and provider-side dynamics, the measurements will be repeated every hour for a period of 2 months (to understand diurnal and mobile variance). Most experiments are very lightweight and will therefore not consume notable proportions of data allowances. The highest overhead tasks are the full fetches and bandwidth probes, and therefore these will only be performed occasionally to support debugging. *This task will produce feedback for MONROE regarding the ease of writing diverse experiments for MONROE and deploying them in an automated fashion.*

Task 2: Data Analysis and Experimental Revisits (Months 6-11)

Task 2 will cover the analysis of data (Objective 2, and MONROE WP3). The bulk of the work in Task 2 will involve extracting insight from the datasets generated in Task 1, culminating in a single Milestone:

Milestone 3 (Month 11): Completion of data analysis to compile a deployment profile of the services studied (e.g., Google, Netflix) across all MONROE nodes and MBB networks, as well as an identified set of key bottlenecks explaining perceived performance.

The attainment of this milestone will focus on two aspects of data analysis. First, we will characterise the deployment, performance and interconnection strategies of all content services under-study from the perspective of MBB nodes. This will involve making empirically-driven observations of infrastructural behaviour. For example, this will involve things like service placement, network interconnectivity etc. Second, our analysis will strive to understand and explain the causes behind good/bad performance. This will arise from a complex interplay between client, network and server attributes. Possible causal attributes include server placement (intra vs. inter domain), poor server selection, time-of-day properties (e.g., peak time congestion), TCP settings (e.g., initial window configuration), peering agreements (e.g., presence at IXPs) and service structure (e.g., use of third party plug-ins). Our analysis will focus on revealing these causal attributes, as well as others. Task 2 will also involve *re-deploying* (a potentially extended) toolbox to collect alternative data to corroborate hypotheses (during Months 8-11). This will allow us to compare the deployment strategy of each service and correlate it with perceived performance in MBB networks. *This task will produce feedback for MONROE regarding the ease of adaptively deploying experiments, as well as MONROE's data management functionality.*

Task 3: Feedback and Reporting (Months 1-12)

Task 3 will focus on addressing Objective 3, providing feedback and recommendations regarding the use of MONROE, as well as offering suggestions for improving MBB and content infrastructure. This will be embodied in two deliverables:

Deliverable 1 (Month 3): First feedback report containing information on challenges faced during the bootstrapping phase of the project, alongside proposals for ameliorations.

Deliverable 2 (Month 12): Final report containing summary of feedback to MONROE, as well as measurement methodology, results and implications.

To achieve these two deliverables, three sub-tasks have been formulated:

Task 3.1: Feedback to MONROE (Months 1-12): Through our work, we will offer detailed feedback on the use of the MONROE testbed. This will be offered throughout the duration of CaMCoW and is intended to feed into MONROE's WP1 and WP4. It will cover how easy it is to deploy the measurement probes, to collect the data, to configure the platform and how reliable the testbed is. Our measurements will also provide critical insight into the user experience of MBB network subscribers (of interest to Telenor) and middlebox usage/optimisation (of interest to Celerway Communications). We will also propose changes and extensions to MONROE. All code developed within CaMCoW will be made available, allowing future users within the MONROE consortium to benefit from it. We intend our feedback and recommendations for extensions to primarily pertain to better automation of experiment execution and data collection. Our team has a wealth of experience in running large-scale measurements. As such, we are well placed to propose potential improvements. It is likely these will relate primarily to *(1)* Reducing experimenter workload when defining and launching probes through the MONROE interface; *(2)* Improving debugging and automated logging of what has occurred within the testbed; *(3)* Understanding and mitigating inter-experiment interference. All of these topics are areas that we have expertise in addressing.

Task 3.2: Recommendations to Network and Content Providers (Months 10-12): Based on the analysis in Task 2, we will formulate recommendations for improving content provision in MBB networks. These will be based on the data analysis in Task 2. The targets of this feedback will be MBB networks and content providers. We will propose means by which these parties can better offer and support service provisioning for their customers.

Task 3.3: Documentation (Months 1-12): The above two bodies of feedback will be provided within two deliverables, as well as code/data documentation for public use. The first feedback report (Deliverable 1) in Month 3 will focus on initial progress, as well as documenting problems with bootstrapping a project on MONROE. This is intended to offer input into improving MONROE accessibility for future users. The final report (Deliverable 2) will primarily focus on; *(1)* Challenges faced during the measurement execution, relating both to MONROE and more general issues; *(2)* The design of our experiments and the results found; *(3)* A set of recommendations for MBB network operators and content providers to improve future service performance; *(4)* A set of recommendations for future developments of the MONROE testbed, including a list of features that retrospectively would have enabled us to more effectively fulfil our experiment's needs; and *(5)* A summary of the key pathways to impact within CaMCoW and suggestions for expanding impact of the MONROE testbed.

Task 4: Dissemination (Months 8–12)

Task 4 will focus on disseminating knowledge achieved via the previous tasks and objectives. This can feed directly into MONROE's WP7. We have a single milestone in this Task:

Milestone 5 (Month 11): We will submit 1x conference paper at a premier networking/measurements conference. It will focus on the impact of peering and interconnection strategies employed by content providers and MBB networks. This paper will characterise and explain the performance of content services in MBB networks.

Section C Requested MONROE Resources

(maximum 1 page)

Please check MONROE resources that will be required for your experiment.

Resources	Required (Yes/No)
Access to mobile nodes	**Yes**
Access to multiple interfaces simultaneously	**Yes**
Kernel modifications	No
Bandwidth intensive tests (e.g. video streaming)	No
Continuous access to the platform (e.g. ping test for a long period)	**Yes**
Access to the data produced by MONROE	**Yes**

Please provide more information on why specific resources will be required for the proposed experiment or extension. Please also specify when and how you will be running experiments on the platform.

As we envisage that network and content service provider strategies will vary heavily based on several factors, it is necessary to get as many samples as feasible. For example, the content provider performance will vary based on the virtual network operator, even when a client is connected to the same physical access point [**12**]. We will adapt our usage of MONROE to reflect the capacity and data allowances on nodes; thus, we will consider this during the collection of data points and ensure that our measurements are not "heavyweight". We plan to run our primary data collection between Months 4 and 8. Between Months 1 and 4 preliminary versions of our experiments will be tested iteratively over MONROE on a smaller scale. We will select a measurement frequency based on the resources and data allowances observed within MONROE. We anticipate that the overhead will be limited as the measurement techniques being employed (e.g., ping) consume marginal resources. We will avoid heavyweight throughput measurements, to alleviate the load on the nodes. These will be used primarily for "debug" purposes when trying to explain performance issues. Only once the techniques have been fine-tuned will we consider expanding to other providers. We also intend to perform iterative experimentation and data collection for the full duration of the project. This will be done to confirm hypotheses that the existing data cannot. This might therefore results in new techniques being utilised, however, the load of these iterative measurement probes will be kept as low as possible. We do not intend to deploy any new MONROE nodes within the project.

Section D Expected feedback to the MONROE Consortium

(maximum 1 pages)

This section contains valuable information for the MONROE consortium and should indicate the expected feedback the MONROE consortium can expect from the use of its platform after carrying out the experiment and/or extension. This information is essential in view of further improving the MONROE platform. Note that providing this feedback is one of the key motivations for the existence of the MONROE open calls.

Dr. Tyson and Prof. Uhlig have vast experience in using, as well as operating, experimental infrastructure. This includes RIPE Atlas, Planetlab, Emulab and various novel measurement methodologies. We are therefore well placed for providing feedback to the MONROE consortium. Specifically, we intend our feedback to focus on the following aspects:

- *Key Improvements:* A primary focus of our proposal is to develop and execute various network- and application-layer measurement techniques. Through this, we will gain insight into MONROE's ability to support these techniques. This will lead to suggestions for potential improvements in various aspects, such as experiment coordination, isolation among network slices, network topology descriptions, management access on slices etc. We will also propose extensions to MONROE's management platform to better enable the automation of measurements. This is something our team has a broad range of experience in.
- *Usage Difficulties:* We will formulate feedback regarding which parts of MONROE are easy/difficult to learn and use. This will be particularly relevant during the first 3 months of the project, where we will aim to provide detailed insight into things that make bootstrapping new experiments most challenging. Where appropriate we will offer inputs to the MONROE wiki to support future users in avoiding pitfalls.
- *Key Limitations:* Through our experiments, we will also identify and highlight fundamental limitations in running these types of experiments on MONROE. These will differ from the Key Improvement as they will focus on fundamental limitations that cannot be achieved using a testbed like MONROE (e.g., types of measurements that cannot be tractably and reliably performed). This will subsequently feed into suggestions regarding how MONROE could be integrated/federated with other testbeds to address such deficiencies.
- *Key resource sharing:* We have a long history of developing automated methodologies for collecting large-scale datasets. We intend to make all code available to the wider MONROE consortium. We wish to pursue this in a well-engineered manner and allow MONROE participants to reuse our code for re-collecting any data we create. These techniques will be transferable to other partners' experiments.
- *Errors:* We are an experienced team of system developers/users, who have a substantial background in debugging. We hope that through our usage of the system, we can assist the MONROE administrators with detecting issues. This will be done in a timely fashion.

The above points will be captured within the final report (Deliverable 2), providing a detailed overview of our feedback. To provide more immediate feedback, we will utilise MONROE's wiki for consortium members to read. This will cover every day experiences of using MONROE. It will also serve as a diary of progress. Through this, we will make feedback easily available to the wider consortium with limited communication overhead. We will establish direct links with the MONROE system developers to report bugs, issues and ideas in real time.

Section E Background and qualifications

(maximum 1 page)

This section describes the proposer and includes an overview of the activities, the proposer's qualifications, technical expertise and other information to allow the reviewers to judge the proposer's ability to carry out the experiment. For proposals that have 2 participants, please clearly describe the qualifications and expertise of each participant and how the two participants complement each other.

CaMCoW will be managed by two investigators at Queen Mary University of London (QMUL). Both have extensive experience in executing and managing Internet measurement-based research projects. They will both contribute to all tasks listed in Section B4.

Dr. Gareth Tyson (PI) is a Lecturer in Networked Systems at QMUL since June 2014. Earlier, he held Research Associate positions at both QMUL (2012-2014) and King's College London (2010-2012). During 2016 he has been a visiting researchers at the Cambridge Computer Lab. He completed his PhD on networked systems at Lancaster University (2006-2010). He has played a critical role in several major national and international projects, including those funded by both the EU (CONTENT, INTERSECTION) and EPSRC (IU-ATC, ITaaU). He has over 750 citations for papers published in a number of premier journals and conferences. These include IEEE/ACM Transactions on Networking (ToN), IEEE Transactions on Computers (TC), Communications of the ACM (CACM), IEEE Journal on Selected Areas in Communications (JSAC), the Internet Measurement Conference (IMC), the ACM World Wide Web Conference (WWW), ACM HotNets and the IEEE International Conference on Network Protocols (ICNP). He has substantial experience in performing network measurements, having published measurement research, for example, on video platforms, content delivery networks, P2P and routing security. These studies have involved a versatile and novel range of measurement techniques. Dr. Tyson is also heavily involved in community and wider dissemination activities. He serves on a wide range of conference program committees (e.g., IFIP Network, IWQoS, ICN) as well as journal review boards (e.g., ToN, TPDS, TC, JSAC, TNSM, ToMM). He has been active in contributing to the IETF in the ICN and GAIA research groups. He recently was the Local Chair for ACM DEV, hosted at QMUL, and is the Local Chair at ACM IMC'17.

Prof. Steve Uhlig (CI) is Professor of Networks at QMUL. Prof. Uhlig has extensive experience in EU project management. He is currently Principal Investigator on the Horizon 2020 ENDEAVOUR project that QMUL is coordinating. He has also participated in several other EU projects, e.g., FP7 projects CHANGE, OFELIA, and COST Action IC0703 "Data Traffic Monitoring and Analysis (TMA)". Prof. Uhlig is the co-author of about 100 publications and 4 patents, including papers at prestigious outlets such as ACM SIGCOMM, ACM IMC, ACM CoNEXT, ACM HotNets and IEEE/ACM Transactions on Networking. Prof. Uhlig has an h-index of 35, with in excess of 4000 citations. He has been on the technical program committee of about 50 international conferences and workshops. He also brings a unique expertise working with all the major players of the Internet ecosystem (ISPs, content delivery networks, and IXPs), and helping them develop mutually beneficial relationships. Prof. Uhlig was with Deutsche Telekom Laboratories for 3 years, partly involved in Software-Defined Networking (SDN), through the FP7 projects CHANGE and OFELIA, working closely with the Palo Alto branch of Deutsche Telekom Laboratories that pioneered SDN. He is also a Guest Professor at the prestigious Chinese Academy of Sciences (CAS), Beijing, China, working on network measurements and SDN. In 2015 he was chair of the ACM SIGCOMM conference, arranged by QMUL in London.

Section F Requested funding

(maximum 1 page)

This section provides an overview of the budgeted costs and the requested funding. A split is made in personnel costs, other direct costs (travel, equipment, etc.) and indirect costs. For proposals that have 2 participants, please clearly indicate the distribution of the costs between the two participants.

Besides the table below, extra information can be provided to support the requested funding and which may help to judge the cost to the MONROE project.

For proposals that include a HW extension to the platform, the cost for this extension should be detailed, including expected costs for subscriptions (when applicable). The cost of MONROE nodes can be estimated as 800 EUR per node. For mobile nodes, special equipment for busses and trucks can be estimated as an additional 100 EUR per node.

Please show your figures in euros (not thousands of euros).

	Total PM	**Cost (€)**
1. Direct Personnel costs	12.6	€ 71,973
2. Other direct costs		€ 8,027
3.Total direct costs (sum of row 1 and row 2)		€ 80,000
4. Indirect costs (25% of row 3)		€ 20,000
5. Total costs (sum of row 3 and row 4)		€ 100,000
6. Requested funding (up to 150000 EUR)		€100,000

The personnel funding requested covers a *single post-doctoral researcher* to be based at QMUL for 12 months. This time period is vital for ensuring that the measurement methodology and data collection can be performed correctly. Dr. Gareth Tyson and Prof. Steve Uhlig will each contribute at least 5% of their time to the project. Prof. Uhlig will dedicate this time in-kind to allow greater funding for the post-doctoral researcher. One internally funded PhD student will also contribute to all Tasks in CaMCoW, supporting the post-doctoral researcher. This internally funded student will enable the ambitious nature of the project to be fulfilled within the budget in the time allotted. They will also personally benefit greatly from access to the MONROE testbed.

The other key costs will cover one high-end computer for the post-doctoral researcher to perform heavy data analytics (approx. € 2000). We have also allocated approximately €5700 for international travel (e.g., conference, review meeting attendance). QMUL will also internally contribute up to €2500 for a further conference trip to report the results of CaMCoW. Approximately €300 has also been requested for national travel to disseminate results within seminars (e.g., at Cambridge, Oxford).

Section H Use of proposal information

In this section the proposing party is asked to include some statements related to sharing information of his proposal within the MONROE consortium.

Proposals are treated in a confidential way, meaning that only successful proposals must be disclosed to the MONROE consortium. Open calls previously organized by other FIRE projects were very successful and have revealed that many submitted non-granted proposals also contain very interesting and valuable information that could be used for setting up collaborations or to extract ideas for further improving the federated test infrastructures. Therefore the MONROE project would like to have the opportunity to collect more detailed information and further use this information, also if the proposal is not selected for funding. In any case, the MONROE consortium will treat all information of a proposal confidentially.

Two types of information usage are envisaged:

- *Information which is part of the Sections A, C and D will be used within the MONROE project as input for tasks related to platform optimizations, sustainability studies, etc. The same information can also be used in an anonymous way to create statistics and reports about this first open call. All proposals submitted to this competitive open call are obliged to allow this form of information access and usage.*
- *Other information belonging to this proposal might also be accessed by the MONROE consortium, if allowed by the corresponding proposer. Any use of such information will be discussed and agreed upon with the proposers. Proposers have the freedom to select if they wish to support this kind of information usage.*

I allow that the material provided in Sections A, C and D of this proposal may be accessed by the MONROE consortium, also if the proposal is not selected for funding. In any case, the MONROE consortium will treat all this information confidentially. It will be used within the MONROE project as input for tasks related to testbed and software platform optimizations, sustainability studies, etc. The same information can also be used in an anonymous way to create statistics and reports about this first open call.	**Yes X**	
Furthermore, I allow that the other parts of this proposal may be accessed by the MONROE consortium, also if the proposal is not selected for funding. In any case, the MONROE consortium will treat all information of this proposal confidentially. Any use of this information will be discussed and agreed upon with the proposers.	**Yes X**	No ☐

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